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USRD Type F63 Transducer

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At the request of the Naval Mine Engineering Facility (NMEF), the Underwater Sound Reference Detachment (USRD) developed a small reversible audio frequency range transducer. The USRD type F63 transducer is designed to meet the specific needs in that it is sensitive and stable with temperature and moderate hydrostatic pressures as required by NMEF to improve their mission capability.

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USRD TYPE F63 TRANSDUCER

INTRODUCTION

A number of small audio frequency range reversible transducers have been available for general use in underwater acoustics during the past several years. In spite of the variety of transducers available today, specific needs still arise for which a suitable transducer does not exist. At the request of the Naval Mine Engineering Facility (NMEF), the Underwater Sound Reference Detachment (USRD) developed a small audio frequency range transducer, the USRD type F63, to meet the specific needs of NMEF.

BACKGROUND

NMEF was using a transducer which consisted of a capped barium titanate cylinder with a 38-mm outside diameter, 38-mm length, and a 3-mm thick wall. The sensitivity was about -199 dB re 1 V/μPa. The end caps were isolated from the cylinder by a mylar film gasket, and had four tie screws passing through the cylinder to hold them in place. This construction was such that the mechanical connection between the cylinder and the end caps was variable and this resulted in pressure instability. It was also susceptible to moisture and was unstable with temperature; the latter being an innate fault of the barium titanate material.

A transducer of approximately the same physical size was needed to replace the old one, but with the added stipulations:

- free-field voltage sensitivity measured at the output terminals of the transducer be ≥ -194 dB re V/μPa

- the sensitivity remain constant with hydrostatic pressures to 689 kPa

- the sensitivity remain stable with temperatures from 0 to 40°C within ±0.2 dB.

THE DESIGN

The transducer shown in Fig. 1 was developed to meet the above requirements and was designated the USRD type F63 transducer. It is a radially polarized capped cylinder of PZT-4 composition (Type I MIL-STD-1376(SHIPS)) fitted with an appropriate underwater connector, and waterproofed by encapsulating in a RHO-C acoustical material (see Appendix A for details). This design principle has proved very successful in a variety of USRD standard transducers. The free-field voltage sensitivity in volts per unit pressure is given by Langevin's [1] equation as

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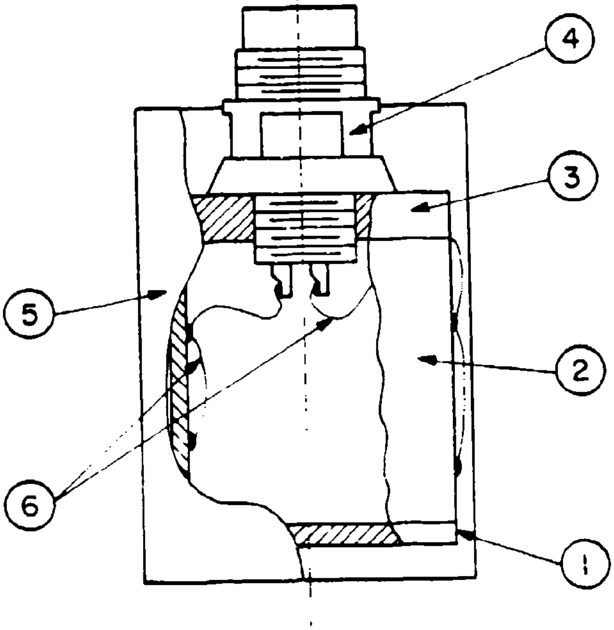
$$e/p_o = -b\left[g_{33}\left(\frac{1-\rho}{1+\rho}\right) + g_{31}\left(\frac{2+\rho}{1+\rho}\right)\right] \quad (1)$$

where $\rho = a/b$ and a and b are the inside and outside radii of the cylinder respectively. Both g_{33} and g_{31} are piezoelectric constants. For the F63, a = 15.9 mm and b = 19 mm; g_{33} is 24.5×10^{-3} Vm/N, and g_{31} is -10.7×10^{-3} Vm/N. The theoretical free-field voltage sensitivity expressed in dB re 1 V/μPa is is -191.3 dB. Since the end cap is bonded to the cylinder by a rigid epoxy-bond, there is a resultant reduction in sensitivity [2] of 1.5 to 2 dB giving a nominal open-circuit crystal sensitivity of about -193 dB re 1 V/μPa. The F63 is virtually the same physical size as the prior NMEF transducer, but twice as sensitive. The capacitance C is given by

$$C = \frac{2\pi\ \epsilon_o\ K_{33}^T\ \ell}{\ell n\ (b/a)} \quad (2)$$

where ϵ_o is permittivity of free space, 8.85×10^{-12} F/m; K_{33}^T is the relative dielectric constant of TYPE I material, 1300; and ℓ is the length 3.8×10^{-2} meters. The proper values in Eq. (2) predict C = 15,414 pF, which compares favorably with actual measured values which were from 14,000 to 16,000 pF.



1 THIN END CAP
2 PIEZOELECTRIC CERAMIC CYLINDER
3 THREADED END CAP
4 UNDERWATER CONNECTOR
5 B.F. GOODRICH RHO-C ACOUSTIC MATERIAL (#35075)
6 ELECTRICAL LEADS

Fig. 1 - F63 line drawing detailing all parts.

OPERATING CHARACTERISTICS

Sensitivity

The typical free-field voltage sensitivity of an F63 measured at the output terminals of the transducer connector is shown in Table 1. Changes in hydrostatic pressure from atmosphere to 689 kPa do not cause any change in the sensitivity. The free-field voltage sensitivity of an F63 transducer measured at the end of a 21-m cable for frequencies of 100 Hz to 30 kHz is shown in Fig. 2.

Table 1. F63 Statistical Data

NO. OF TRANSDUCERS CALIBRATED	TEMPERATURE (°C)	MEAN SENSITIVITY IN dB re 1 V/μPa	STANDARD DEVIATION IN dB
11	0	-193.2	0.3
36	1	-193.2	0.3
15	3	-193.0	0.3
6	22	-193.3	0.1
53	26	-193.5	0.3
9	40	-193.4	0.2

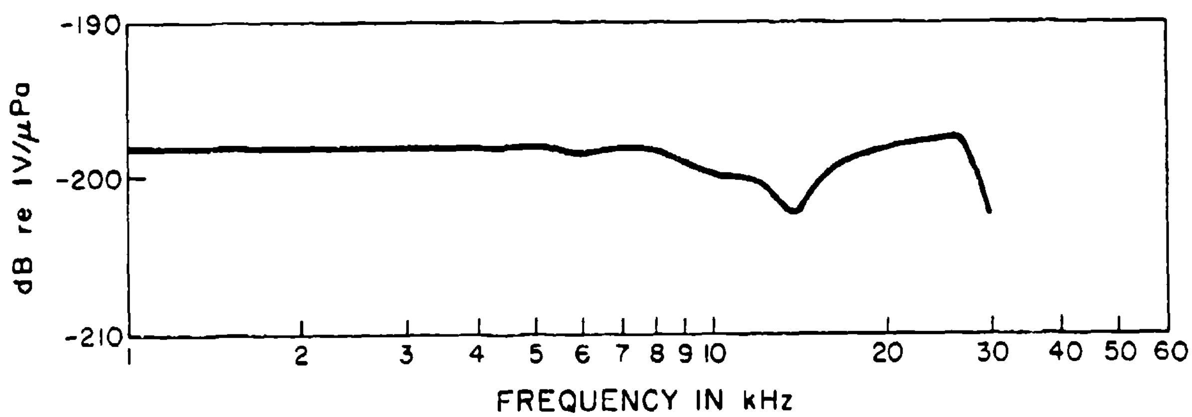


Fig. 2 - Free-field voltage sensitivity of an F63 transducer (open-circuit voltage measured at the end of a 21-m cable).

Transmitting Voltage and Current Responses

Transmitting responses are shown in Figs. 3 and 4. The indicated values were measured in open water at 11°C. Since the sensor uses TYPE I material, the transducer should have a linear output with driving voltage to about 1000 V with a continuous wave signal.

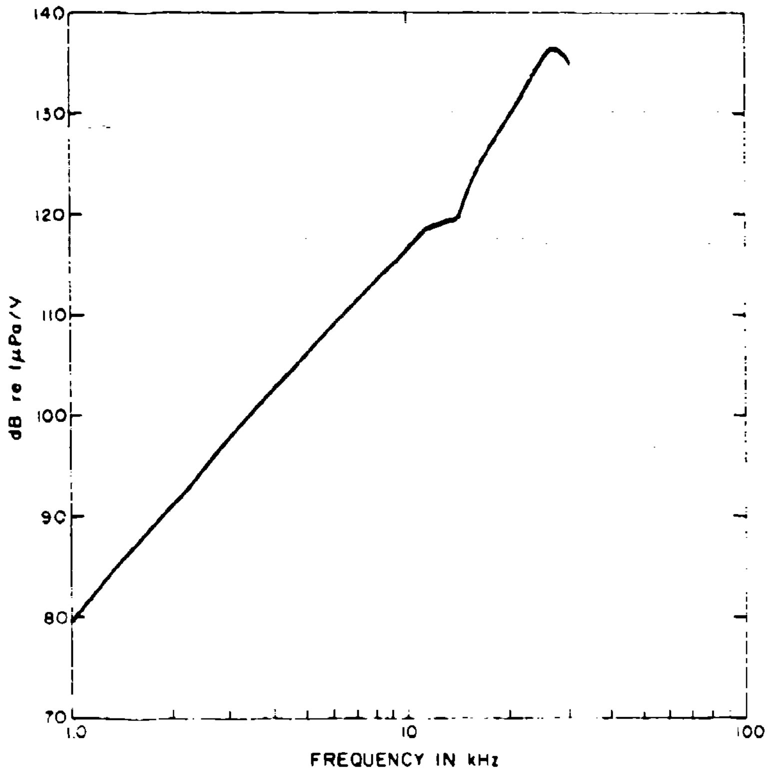


Fig. 3 - Transmitting voltage response, type F63 transducer (pressure at 1 m for 1 V applied at the end of a 21-m cable).

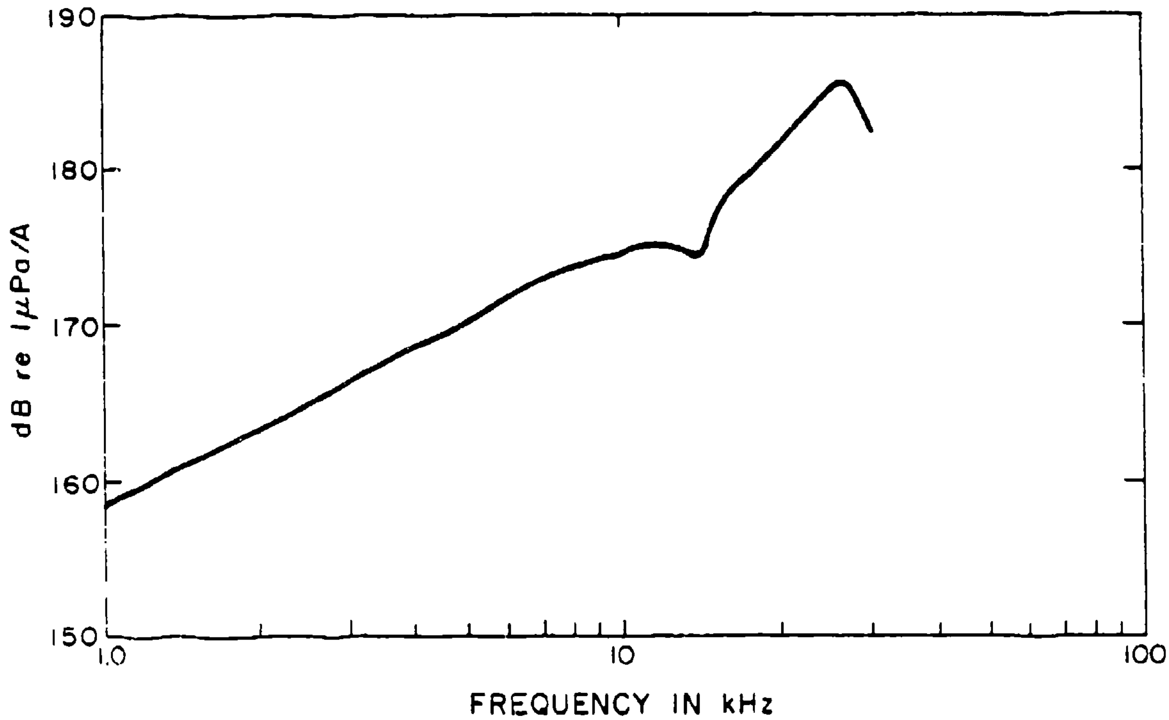


Fig. 4 - Transmitting current response, type G63 transducer (pressure at 1 m for 1 A applied at the end of a 21-m cable).

Impedance

Impedance values are shown in Fig. 5. As expected from a ceramic transducer operating below resonance, the impedance is mostly reactive.

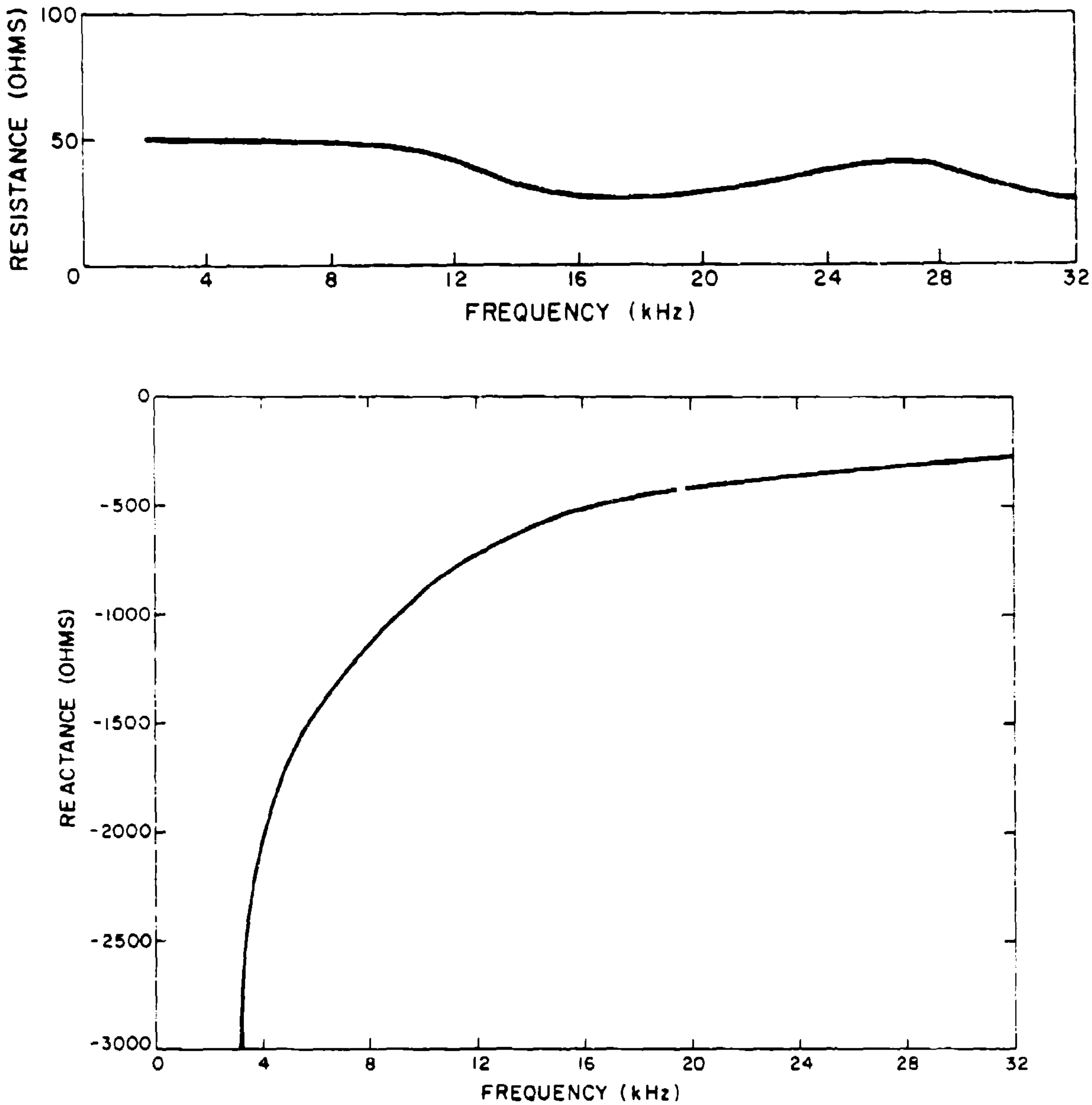


Fig. 5 - Typical resistance and reactance of a type F63 transducer as a function of frequency.

Directional Characteristics

The transducer is omnidirectional within 1 dB in the horizontal (XY) plane at frequencies to 20 kHz. The directivity in the vertical plane (XZ) is shown in Figs. 6a, 6b, and 6c for frequencies of 10, 20, and 25 kHz.

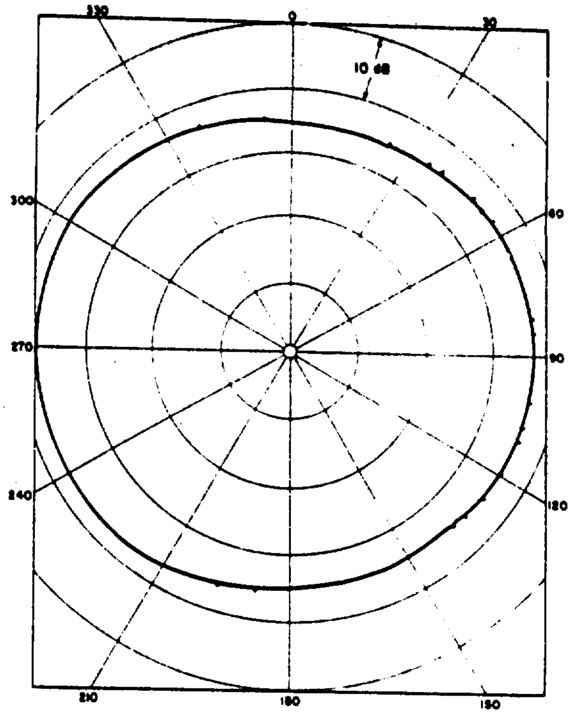


Fig. 6a - Directivity in XZ plane at 10 kHz.

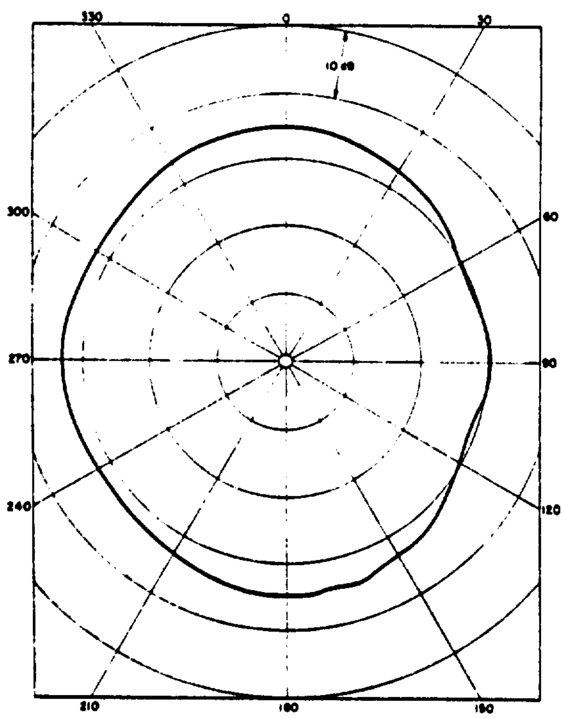


Fig. 6b - Directivity in XZ plane at 20 kHz.

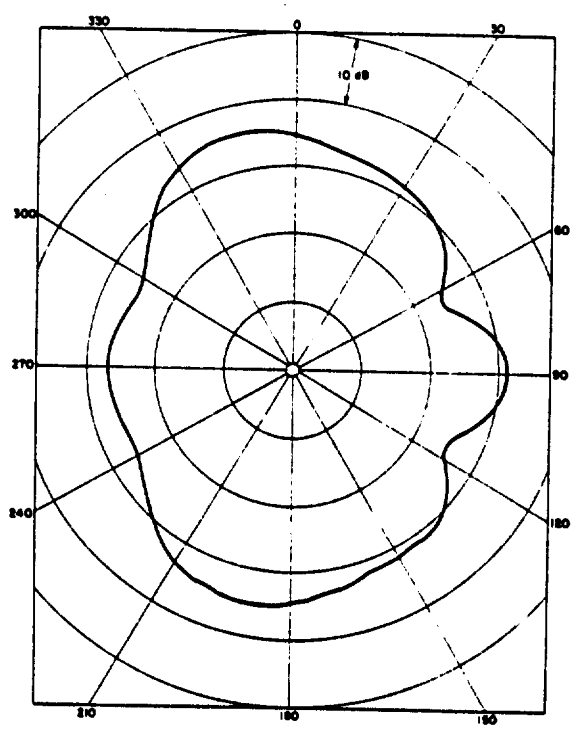


Fig. 6c - Directivity in XZ plane at 25 kHz.

STATISTICAL DATA

Over sixty F63 transducers are presently in service. Most of these were calibrated in the USRD System K as a function of temperature at a hydrostatic pressure of 349 kPa. The measurement system has a resolution of 0.1 dB and repeatability of measurements of ±0.1 dB.

The sensitivity values given in Table 1 are the open-circuit voltage sensitivity measured at the output terminals of the transducer at frequencies well below resonance. The mean sensitivity and standard deviation were calculated in V/µPa and then converted to dB for convenience.

CONCLUSION

The USRD type F63 transducer is well suited for general use in the audio frequency range. It is stable with temperature changes as required and with moderate hydrostatic pressures. It meets the needs of NMEF and has improved its mission capability.

REFERENCES

1. R.A. Langevin, "The Electro-Acoustic Sensitivity of Cylindrical Ceramic Tubes," J. Acous. Soc. Am. 26, 421-427 (1954).

2. R.T. Winnicki and S.E. Guyer, "Geometric Factors Affecting Hydrophone Performance," J. Acous. Soc. Am. 61, 876-881 (1977).

APPENDIX A

CONSTRUCTION OF F63 TRANSDUCER

The F63 transducer is constructed (Fig. 1) as follows:

1. The ceramic cylinder, having been checked for capacitance, resistance, dissipation factor, and size, is then notched and cleaned. The notch is approximately 1 mm × 1 mm, on one end of the cylinder, cut through from the outside to the inside. The silvered electrode is dressed back approximately 2 mm all around the notch on the inside of the cylinder. A clean tinned solid copper lead is then bonded into the notch with Dexter Corp. EA6 Epoxy. When this has cured, the end on the outside of the cylinder is bent upward and soldered to the outer silvered electrode which is the negative, or ground, using 2% silver bearing solder to prevent separating the electrode from the ceramic. A lead is then soldered to the inner silvered electrode which is the positive, or high, electrode with the same solder.

2. The thin aluminum end cap is stamped with the model and serial numbers of the hydrophone. It, and the thicker end cap, are then anodized, per MIL-A-8625C, TYPE II, Class 1, nominally 0.01-mm thick. The anodizing prepares the surfaces for bonding with the EA6 Epoxy that will hold them on the cylinder, and also for adhesion of the primer, which will be applied later. The thick end cap then has the connector (Rochester Corp. bulkhead Receptacle Type XSJ-3-BCR) installed. This subassembly is then bonded to the cylinder with EA6 Epoxy. When this joint has cured, the leads from the silvered electrodes are soldered to the proper pins in the connector. The end cap is then bonded to the open end of the cylinder, using EA6 Epoxy. After this joint has cured, the entire assembly is cleaned and degreased prior to priming.

3. The priming system used is a two-part system produced by the Hughson Chemical Company. The first part, Chemlok 205, is a rubber-to-metal primer and should be applied sparingly and allowed to dry thoroughly. The second part, Chemlok 236, is a rubber-to-rubber primer, applied liberally, and allowed to dry thoroughly. The sensor element assembly is now ready to be potted.

4. The mold must be prepared to form the potting compound to the desired shape. The mold finish should be very smooth, and free of nicks or dents. If surface irregularities are present, sections may be pulled out of the potting when the mold is opened. Crown Industrial Products Co. #6075 Dry Film Lubricant and Mold Release Agent are applied to the mold to help in removing the finished part.

5. Place the sensor element assembly in the mold and fill the mold with B.F. Goodrich Company RHO-C acoustical material (formerly 35075 Castable RHO-C) as follows:

   a. Bring temperature of mold assembly and part 1 of potting compound to 80°C.

   b. Mix parts 1 and 2 of the potting compound according to manufacturer's recommendations, and degas for 15 minutes at 80°C in a vacuum of 10^{-3} torr minimum.

   c. Remove from vacuum and fill mold cavity with the mixed potting compound. Exercise care when filling mold to avoid as much entrapped air as possible.

   d. Place filled mold back into 80°C vacuum chamber and degas for 20 minutes with a 10^{-3} torr vacuum minimum.

   e. Release vacuum and cure assembly for 24 hours at 80°C.

   f. Remove mold from vacuum oven, cool, and carefully remove the hydrophone. Clean all excess compound from edges of mold cavity. Extreme care must be taken in removing the hydrophone from the mold. Using too much force can break the connector off the hydrophone.

6. After 24 hours at room temperature, measure capacitance, dissipation factor, resistance, and prepare for calibration.